INTRODUCTION:

The spinal cord and the brain both develop from the neural tube of the embryo, with the anterior ending enlarging, folding, and becoming more complex to form the brain. Like the brain, the spinal cord consists of both **gray matter** (neuron cell bodies, unmyelinated axons, dendrites, and glia) and **white matter** (myelinated neuron processes and glia), but its structure is quite different. The white matter is located in the superficial regions of the spinal cord and is organized into **tracts**, large bundles of axons which carry motor information and sensory information to and from the higher-level processing centers of the brain. The gray matter, deeper within the spinal cord, contains the neuron cell bodies which coordinate this transfer of information as well as forming parts of various **spinal reflexes**. The elongated structure of the spinal cord and its location in the back provide lots of room for nerves to connect to it.

Your spinal cord is approximately the diameter of your finger, and it extends from the foramen magnum in the occipital bone of your skull to the upper part of the lumbar region of your back, where it ends in a cone-shaped region called the **conus medullaris**. Along the way, it gives off 31 pairs of **spinal nerves** which pass through the **intervertebral foramina** and carry motor (efferent) and sensory (afferent) information to and from the rest of the body. Its diameter is somewhat larger in the cervical, lumbar, and sacral areas, which send and receive information to and from the upper and lower limbs.

A few months before you were born, your spinal cord was the same length as the **vertebral column** surrounding it, and each spinal nerve extended straight out laterally through an intervertebral foramen. However, as you continued to grow, your spinal cord did not grow as quickly as the vertebrae around it. As a result, your spinal cord is now at least thirty centimeters shorter than the vertebral column. Although the spinal cord has cervical, thoracic, lumbar, sacral, and coccygeal regions, these no longer lie next to the corresponding vertebrae. In fact, the sacral and coccygeal regions of the spinal cord reach only into the upper lumber regions of the vertebral column. This means that spinal nerves which emerge from the inferior, or caudal (“tail”) end of the spinal cord must travel inferiorly within the vertebral canal for some distance before they can exit through the appropriate intervertebral foramina. This group of nerves running from the spinal cord to the intervertebral foramina must have reminded someone of the course hairs in a horse’s tail because they are collectively called the **cauda equina**.

Just like the brain, the spinal cord is surrounded by **meninges** consisting of **pia mater**, **arachnoid mater**, and **dura mater**. The **epidural**, **subdural**, and **subarachnoid spaces** are also present, and the last of these contains cerebrospinal fluid (CSF), just as it does around the brain. Thus, the spinal cord “floats” in subarachnoid CSF just like the brain does. In addition, since the subarachnoid space surrounding the cauda equina reaches all the way to the bottom of the sacrum, CSF can be safely withdrawn (a “lumbar puncture” or “spinal tap”) from the lower lumbar regions of the back, or an anesthetic can be injected into it (“spinal anesthesia”) without an risk of hitting the spinal cord itself with the needle.
STRUCTURE OF THE SPINAL CORD:

1: Figures 13.1 and 13.10 in your Saladin textbook presents a longitudinal view of the human spinal cord with the surrounding meninges opened to expose it. Identify the spinal cord with cervical and lumbar enlargements. Identify the dura mater and arachnoid mater and understand where the pia mater is. Identify 31 pairs of spinal nerves as they emerge from the spinal cord, and notice how all except the uppermost few must descend within the subarachnoid space before they can pass through the arachnoid mater and dura mater at the level of their intervertebral foramina.

The spinal cord is considered to have cervical, thoracic, lumbar, sacral, and coccygeal levels where the nerves of these regions connect to it. The cervical level of the spinal cord is defined as the portion where cervical nerves connect, the thoracic regions of the spinal cord is defined as the portion where thoracic nerves attach to it, etc. Trace the spinal nerves back to the spinal cord and identify each of these regions.

Identify the conus medullaris (medullary cone) and the cauda equina. Be sure you understand how spinal nerves pass through intervertebral foramina (review the structure of vertebrae, keeping in mind that the intervertebral foramen is formed by the superior and inferior notches of two adjacent vertebrae).

With other members of your lab group, discuss the following questions:

- The spinal cord connects directly to which part of the brain?
- What is the cauda equina composed of?
- The cauda equina is located in which meningeal space?
- The adult spinal cord ends inferiorly next to which vertebra?

2: Figure 13.2 presents a cross-sectional view of the human spinal cord. Be sure you can differentiate between gray matter and white matter (review the definitions and functions of gray matter and white matter in your textbook if necessary). Identify the following structures:

Anterior (ventral) horns of gray matter
Posterior (dorsal) horn of gray matter
Lateral horn of gray matter
Anterior (ventral) column of white matter
Posterior (dorsal) column of white matter
Lateral column of white matter
Anterior median fissure
Posterior median sulcus
Anterior (ventral) root of the spinal nerve
Posterior (dorsal) root of the spinal nerve
Central canal
Posterior (dorsal) root ganglion
Realize that this pattern continues the full length of the spinal cord: an inner core of gray matter surrounded by white matter, with the dorsal root and the ventral root of a spinal nerve connecting on each side. You would see the same general appearance if you examined a cross section of the spinal cord from any level.

3: Obtain a model of the spinal cord in cross-section. Identify the:
   - Gray matter and white matter
   - Anterior, posterior, and lateral horns of gray matter
   - Anterior, posterior, and lateral columns of white matter
   - Anterior median fissure and posterior median sulcus
   - Anterior (ventral) and posterior (dorsal) roots of a spinal nerve
   - Central canal
   - Posterior (dorsal) root ganglion

Notice the arteries and veins which run longitudinally along the spinal cord and give off lateral branches. What space (relative to the meninges) are these lying in?

MENINGES AND SPACES:

4: On Figures 13.2 of your Saladin text, note that the anterior and posterior roots of the spinal nerves lie within the vertebral canal along with the spinal cord, and that these two roots join together as they pass through the intervertebral foramen.

Identify the three layers of the meninges which surround the spinal cord – the pia mater, arachnoid mater, and dura mater. Identify the spaces between them.

- Close your book. From memory, identify in order the layers of the meninges and the spaces between them, starting closest to the nervous tissue of the spinal cord.

   SPINAL CORD (nervous tissue)
   __________________________ mater
   __________________________ space
   __________________________ mater
   __________________________ space
   __________________________ mater
   __________________________ space

   VERTEBRAE (bone)
5. Examine Figure 14.7 of your Saladin text and note how the subarachnoid space surrounding the brain is continuous with the subarachnoid space surrounding the spinal cord. You should be able to visualize how ALL layers of the meninges and the spaces associated with them are continuous between the brain and spinal cord.

All layers of the meninges and all of the spaces associated with them extend past the end of the spinal cord itself in the lumbar region of the back, all the way to the end of the sacrum. Thus, the cauda equina (roots of spinal nerves) are surrounded by pia mater and are floating in the cerebrospinal fluid of the subarachnoid space.

- Physicians and anesthetists often insert a needle into the subarachnoid space to withdraw some cerebrospinal fluid or to inject something into it (such as an antibiotic or anesthetic drug). This is done by a “lumbar puncture” in which the needle is placed between the third and fourth lumbar vertebrae. Explain to other members of your lab group why this is considered a “safe” place to insert a needle into the vertebral canal and meningeal spaces without damaging the spinal cord.

6: On yourself (using a mirror) and/or another person, identify the level of your neck where the foramen magnum is located and the spinal cord thus begins. Identify lumbar vertebrae 1 and 2, where the spinal cord ends at its conus medullaris. Identify the space between the third and fourth lumbar vertebrae where a lumbar puncture could be done. Identify the end of the sacrum where the meninges and their associated spaces end. Note: This will require the removal of part of your clothing, so it should be done at home rather than in lab.

TRACTS OF THE SPINAL CORD

The white matter of the spinal cord is organized into tracts, which are groups of axons with the same origin, terminus, and function (review the structure of a neuron if necessary). Specific tracts are not something you can easily differentiate from one another with the naked eye. These tracts are called ascending tracts if they carry sensory (afferent) information from a lower level of the spinal cord to a higher level of the spinal cord or the brain, and they are called descending tracts if they carry motor (efferent) information from the brain or higher level of the spinal cord to a lower level.

Tracts are generally named according to where they begin and where they end, as well as which area of the spinal cord they are found in. Thus, the posterior spinocerebellar tract is located in the posterior column of the white matter and carries information from the spinal cord to the cerebellum of the brain. The lateral corticospinal tract is located in the lateral column of the white matter and carries information from the cerebral cortex to the spinal cord. Many, but not all, tracts cross from one side of the central nervous system (brain or spinal cord) to the other side as they ascend or descend. Thus, much of the motor and sensory control of the right side of your body is processed by the left side of the brain, and vice versa. When a spinal tract crosses over to the opposite side, this is referred to as decussation.
7. A number of ascending and descending tracts are illustrated on Figure 13.4, 13.5, and 13.6 in your textbook if you would like to study them. However, you will not be responsible for identifying all of them. Instead, you should identify one ascending tract and one descending tract of the human spinal cord and learn its location in the spinal cord, its origin (where the cell bodies of its neurons are located), and its termination (where its axons for synapses with other neurons).

Name of ascending tract: ________________________________
Location in the spinal cord ________________________________
Origin __________________________________________________
Termination _____________________________________________

Name of descending tract: ________________________________
Location in the spinal cord ________________________________
Origin __________________________________________________
Termination _____________________________________________

With other members of your lab group, discuss the following questions:

- What would happen if all of your ascending spinal cord tracts were destroyed?
- What would happen if all of your descending spinal cord tracts were destroyed?
- What would happen if all of your ascending and descending tracts were destroyed?
SPINAL NERVES:

8. If you examine Figures 13.1, 13.2, and 13.10 again, you see the spinal nerves through which the spinal cord communicates with the rest of the body. There are 31 pairs of spinal nerves which pass through the intervertebral foramina between the pedicles of vertebrae to get in and out of the vertebral canal. These nerves are named according to which intervertebral foramen they pass through. For example, spinal nerve cervical-5 passes through the intervertebral foramen above the vertebra with the same name - cervical-5.

All of the spinal nerves are mixed nerves: that is, they contain some neurons carrying afferent information and other neurons carrying efferent information. Close to the spinal cord, however, afferent and efferent neurons are physically separated into the anterior (ventral) and posterior (dorsal) roots you observed previously. The anterior root of each spinal nerve carries axons of efferent neurons whose cell bodies are located in the anterior and lateral horns of the spinal cord, while the posterior root of each spinal nerve carries axons of afferent neurons whose cell bodies are located in the dorsal root ganglion and are sending information into the posterior horn of the spinal cord. The two roots join to form the mixed nerve as it passes through the intervertebral foramen.

Almost immediately after passing through the intervertebral foramen the spinal nerve divides into two uneven divisions, or rami: a larger anterior (ventral) ramus and a smaller posterior (dorsal) ramus. Both of these are mixed, carrying both afferent and efferent information.

The posterior ramus of each spinal nerve goes to skin and muscles of the back at the level it originates, but the functions of anterior rami are more complex. In the thoracic region, the anterior rami of nerves T2 through T12 continue around the body wall, lying just underneath the ribs and called intercostal nerves. The anterior rami of other spinal nerves join together to form plexuses which serve larger areas of the body. Be sure you can identify anterior and posterior rami of the spinal nerves on Figures 13.2, 13.11, and 13.13.

With other members of your lab group, discuss the following questions:

- How many spinal nerves connect to the cervical region of the spinal cord?
- How many spinal nerves connect to the thoracic region of the spinal cord?
- How many spinal nerves connect to the lumbar region of the spinal cord?
- How many spinal nerves connect to the sacral region of the spinal cord?
- How many spinal nerves connect to the coccygeal region of the spinal cord?
- What would happen if the posterior ramus of a spinal nerve were damaged?
PERIPHERAL NERVES:

As they emerge from the intervertebral foramina, the anterior rami of all 31 pairs of spinal nerves branch and recombine with each other to form the peripheral nerves which will supply both motor (efferent) and sensory (afferent) innervation to specific parts of the body. As they do so, they change names. Rather than having segmental names (e.g. “thoracic nerve #5”), they are generally named according to which part of the body they supply (e.g. “intercostal nerve #5”; “ulnar nerve”, “femoral nerve”).

Each nerve consists of the axons of hundreds or thousands of individual neurons, interspersed with layers of connective tissue to protect them. These axons can be very long: for example, one axon must reach all the way from the lumbar region of your spinal cord (where its cell body is located) to the muscles in your foot which abduct and adduct your toes; one axon (actually called a “peripheral process”) must carry sensory information the same distance from your foot back to your spinal cord.

The anterior rami of most spinal nerves branch and recombine to serve various regions of the body by forming plexes (singular: plexus). For example, the ventral rami of five spinal nerves (Cervical nerves 5, 6, 7, 8, and Thoracic nerve 1) branch and recombine in the brachial plexus to form nearly thirty different peripheral nerves which supply the shoulder and arm. Dorsal rami of spinal nerves never enter into plexes in the human.

9: Examine Figures 13.11 and 13.13 in your Saladin textbook. Be sure you can identify the separation of dorsal and ventral rami. Be sure you understand both the structural and functional differences between a root and a ramus of a spinal nerve so you do not confuse these.

10: Examine Figure 13.10 in your textbook showing the formation of plexuses from the anterior rami of spinal nerves. You should know which spinal nerves contribute to each plexus and the general area of the body which each one serves.

<table>
<thead>
<tr>
<th>Plexus:</th>
<th>Formed by anterior rami of which spinal nerves:</th>
<th>Area of body served:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brachial:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumbar:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sacral:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notice on Figure 13.10 that there is not a plexus of thoracic nerves. As shown on Figure 13.13 the anterior rami of spinal nerves Thoracic 2 through Thoracic 12 simply continue around the body wall as the intercostal nerves because they lie in the intercostal spaces between the ribs.
11: Using Tables 13.3-13.6 and Figures 13.14, 13.15, 13.17, and 13.18 in your Saladin text as a reference, identify the following peripheral nerves on the large charts hanging in the lab. Realize that these are just a VERY tiny fraction of the large number of nerves in the human body.

- Axillary nerve
- Common fibular (peroneal) nerve
- Femoral nerve
- Median nerve
- Musculocutaneous nerve:
- Phrenic nerve
- Radial nerve:
- Sciatic nerve: Note: The sciatic nerve is really the tibial and common fibular nerves travelling together until they reach the popliteal region, where they separate
- Tibial nerve
- Ulnar nerve

12: On yourself and/or another person, identify the location of each of the plexes listed above in #10 and each of the nerves listed in #11. Draw these directly on the skin using a washable marker. Note: This will require the removal of clothing, so it should be done at home.

SPINAL REFLEXES:

While tracts of the spinal cord carry information between the brain and the spinal cord, not all functions of the nervous system require this communication. The gray matter of the spinal cord can also coordinate many involuntary spinal reflexes, in which we can rapidly respond to stimuli without information having to pass into or out of the brain. Afferent signals enter through spinal nerves, are processed by the spinal cord, and efferent signals leave through spinal nerves. Since the brain is not involved in spinal reflexes, they remain even if the spinal cord is completely cut in an accident or in the case of severe brain injury.

There are five parts of a reflex pathway, or reflex arc, which are discussed in your Saladin text and shown in Figures 13.20, 13.22 and 13.23:

1) A receptor, which detects some stimulus (pain, temperature, muscle stretch, etc.)

2) Afferent neurons which carry sensory information toward the central nervous system. Cell bodies of these neurons are located in dorsal root ganglia.

3) The integration center, consisting of one or more synapses in the gray matter of the spinal cord. These may involve interneurons (i.e., association neurons).

4) Efferent neurons which carry motor information away from the central nervous system. Their cell bodies (like all spinal efferent neurons) are located in anterior or lateral horns of the gray matter. Some of these efferent neurons are stimulated in the integration center while others are inhibited.

5) The effector, consisting of the myocytes, glands, etc. which produce the physical response. Most of these will be on the same side of the body as the stimulus was received (called an ipsilateral response) but some may be on the opposite side (a contralateral response).
TESTING SPINAL REFLEXES:

In order for a reflex to work properly, all of these components must be present. The more association neurons which are involved, the slower the reflex will occur. Humans also have cranial reflexes, in which information passes in and out of the brain through cranial nerves but is not processed by its “higher” regions.

Even though they are not directly involved in reflexes, higher centers in the brain can often influence them by facilitating (speeding up or making stronger) or inhibiting (slowing or making weaker) the reflexive response to a stimulus. You have undoubtedly had your reflexes tested by a physician or nurse, and they are looking at both whether a reflex is present and how strong it is. You should understand why the absence of a spinal reflex usually indicates damage to one of its five components, while a change in the intensity of a spinal reflex (either stronger or weaker) usually indicates damage to either the brain or the spinal cord superior to the integration center for that particular reflex.

You will test four of your lab partner’s spinal reflexes in which the stimulus consists of stretching a muscle, to which it responds by contracting. There are many such stretch reflexes in the human body - in fact, all of your skeletal muscles use this mechanism to constantly adjust their tension. The receptors for a muscle stretch reflex are called muscle spindles (see Figure 13.21 and 13.22 in your Saladin text). These consist of specialized myocytes called intrafusal myocytes or fibers which are embedded within muscle along side the “regular”, or extrafusal myocytes, and are thus stretched as the organ stretches. When this occurs, they send electrical signals (action potentials) through the afferent neurons which form the afferent limb of the reflex. The efferent limb of the reflex carries action potentials out to the extrafusal myocytes, stimulating them to contract. This decreases the stretch on the intrafusal myocytes, thus decreasing the stimulation of the stretch reflex.

We will also test one spinal reflex in which cutaneous receptors of the foot are stimulated, to which it responds by stimulating the muscles which flex the toes.

13: Patellar or Quadriceps ("knee-jerk") Reflex

1) Have your partner sit comfortably on the lab table with his or her legs free and relaxed.

2) Sharply strike the quadriceps tendon just below the patella with a reflex hammer. This stretches the quadriceps muscle, which should respond by reflexively contracting and extending the lower leg.

3) Trade roles and have your lab partner test your patellar reflex.
14: **Achilles Tendon (“ankle-jerk”) Reflex**

1) Have your partner take off the shoe and sock of one foot and kneel comfortably on a chair or the lab table with the foot hanging free.

2) With a reflex hammer, firmly and sharply strike the middle of the Achilles tendon. This stretches the gastrocnemius and soleus muscles, which should respond by reflexively contracting and extending the foot.

3) Trade roles and have your lab partner test your Achilles tendon reflex.

15: **Triceps Brachii Reflex**

1) Have your partner lie down comfortably on the lab table, face up with the elbow flexed so the arm rests loosely across the abdomen.

2) With a reflex hammer, firmly and sharply strike the tendon of the triceps brachii muscle just above the elbow. This stretches the triceps brachii muscle and it should respond by reflexively contracting. However, this is usually a weak reflex so your lab partner will feel the muscle twitch but the lower arm will probably not visibly move.

3) Trade roles and have your lab partner test your triceps brachii reflex.

16: **Biceps Brachii Reflex**

1) Have your partner sit comfortably on a chair with her or his arm resting comfortably on the lab table.

2) With your thumb or forefinger, press down on the tendon of the biceps brachii muscle in the middle of the cubital fossa, then strike this finger with the reflex hammer. This stretches the biceps brachii muscle and it should respond by reflexively contracting. However, this is usually a weak reflex so your lab partner will feel the muscle twitch but the lower arm will probably not move visibly.

3) Trade roles and have your lab partner test your biceps brachii reflex.

*With other members of your lab group, discuss the following questions:*

- *What information would it give your doctor if you did not have a patellar reflex?*
- *What information would it give your doctor if you did not have an Achilles tendon reflex?*
- *What information would it give your doctor if you did not have a triceps brachii reflex?*
- *What information would it give your doctor if you did not have a biceps brachii reflex?*
17: **Plantar (“Babinski”) Reflex**

This is used as an important neurological test for spinal cord damage because it gives an easily detectable abnormal response if the spinal cord has been injured.

1) Have your partner lie comfortably on the lab table with the shoe and sock removed from one foot. This foot should extend freely over the edge of the table.

2) Firmly draw the handle of the reflex hammer along the lateral border of the sole of the foot, beginning at the heel and moving toward the big toe. The normal response is for the toes on that foot to flex (curl down) and adduct (move closer together). If, however, there is damage to the lateral corticospinal tract by which the brain stimulates skeletal muscles to contract, you will instead get extension and abduction of the toes.

3) Trade roles and have your lab partner test your plantar reflex.

*With other members of your lab group, discuss the following questions:*

- What information would it give your doctor if you did not have ANY Babinski reflex on either foot?

- What information would it give your doctor if you had a normal Babinski reflex on one foot and an abnormal (extension) reflex on the other foot?

18: Using Figures 13.20 and 13.23 in your text if necessary, identify each of the five parts of a reflex arc listed above for each of these reflexes you just tested.

**NERVES OF THE CADAVER**

19. One cadaver should be supine (face up). Identify the *medial*, *lateral*, and *posterior cords* of the brachial plexus. Identify the *Musculocutaneous nerve*, *Median nerve*, *Ulnar nerve*, *Radial nerve*, *Axillary nerve*.

On the front of the thigh, identify the *Femoral nerve*
With other members of your lab group, discuss the following questions:

- What would be your symptoms if you damaged your musculocutaneous nerve?
- What would be your symptoms if you damaged your ulnar nerve?
- What would be your symptoms if you damaged your median nerve?
- What would be your symptoms if you damaged your radial nerve?
- What would be your symptoms if you damaged your femoral nerve?

Note: for each of those, be sure to include the effects on both motor function and sensory function if the nerve were damaged